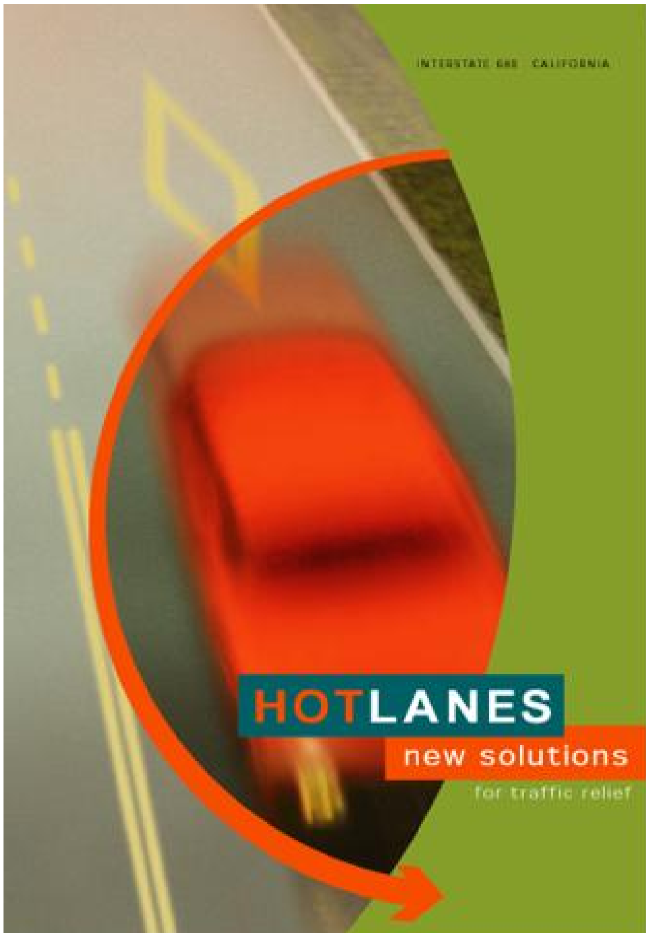

Southbound I-680 Smart Carpool Lane Communications System Plan

Submitted to:

Alameda County
Congestion Management
Agency

Submitted by the
Partnership Team of:

ENGINEERS
PLANNERS
ECONOMISTS
Wilbur Smith Associates

IBI GROUP

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1. INTRODUCTION

1.1 BACKGROUND

The I-680 Smart Carpool Lane is being planned for deployment on the southbound lane of the I-680 freeway in Alameda County between the Route 84 on-ramp and the Calaveras Route 237 Interchange. This lane will be open to single-occupant vehicles (SOVs) that elect to pay a toll. Toll collection in this lane will be supported by FasTrak, the fully automated non-invasive electronic toll system (ETS) currently in use on the Bay Area Toll Bridges.

The I-680 ETS will consist of roadside equipment for the monitoring of traffic flow, control of dynamic message signs and the detection of FasTrak transponders. The roadside equipment will be connected to a central computer system (CCS) via a communications system that will handle the data collection and trip processing. The I-680 ETS CCS will be located at the Toll Data Center (TDC), which will be under the responsibility of the Joint Powers Authority (JPA). In addition, the Bay Area Toll Authority (BATA) back office system, which provides FasTrak customer service and account management functions, will process the I-680 toll transactions. Therefore, the BATA Regional Customer Service Center (RCSC) will also be connected to the TDC via a dedicated communications link. Due to the importance of monitoring traffic conditions in the Smart Carpool Lane in real time and of collecting toll and trip information in a timely manner, a reliable, secure and highly available communications network is essential to the success of the overall program.

This document will identify the communication configuration and requirements between system nodes necessary to satisfy the overall requirements of the I-680 Smart Lane system. The system nodes are:

- The Tolling Zones (TZ);
- Vehicle Detection Stations (VDS)
- The Toll Data Center;
- The Caltrans Traffic Management Center (TMC);
- The BATA RCSC; and
- Other entities that might be required.

1.2 OBJECTIVES

The primary objectives of this communications plan document are to identify and assess the different communication options that could be deployed between the I-680 SMART Lane ETS nodes. At a minimum, the objectives would consist of the following:

- Identify all locations and systems that need to be connected as part of the I-680 Smart Lane application;
- Identify the data and information which needs to be transmitted between the various subsystems of the Smart Lane application;

- Evaluate communication architecture and topology options to securely connect these application nodes;
- Evaluate communication transmission technologies to identify the most technically efficient, cost-effective, secure, and viable communication network environment;
- Develop candidate network architectures for possible future consideration; and
- Identify the next steps necessary in the communications system design process to advance the I-680 Smart Lane Project.

2. COMMUNICATIONS SYSTEM REQUIREMENTS

2.1 LOGICAL COMMUNICATION NODES

At a minimum, secure, reliable and highly available communications will be required among the following system nodes:

- Tolling Zone Subsystem Nodes;
- Remote Vehicle Detection Stations;
- Toll Data Center Node;
- Caltrans TMC Node;
- BATA RCSC Node; and
- JPA/Smart Lane User Information Node(s).

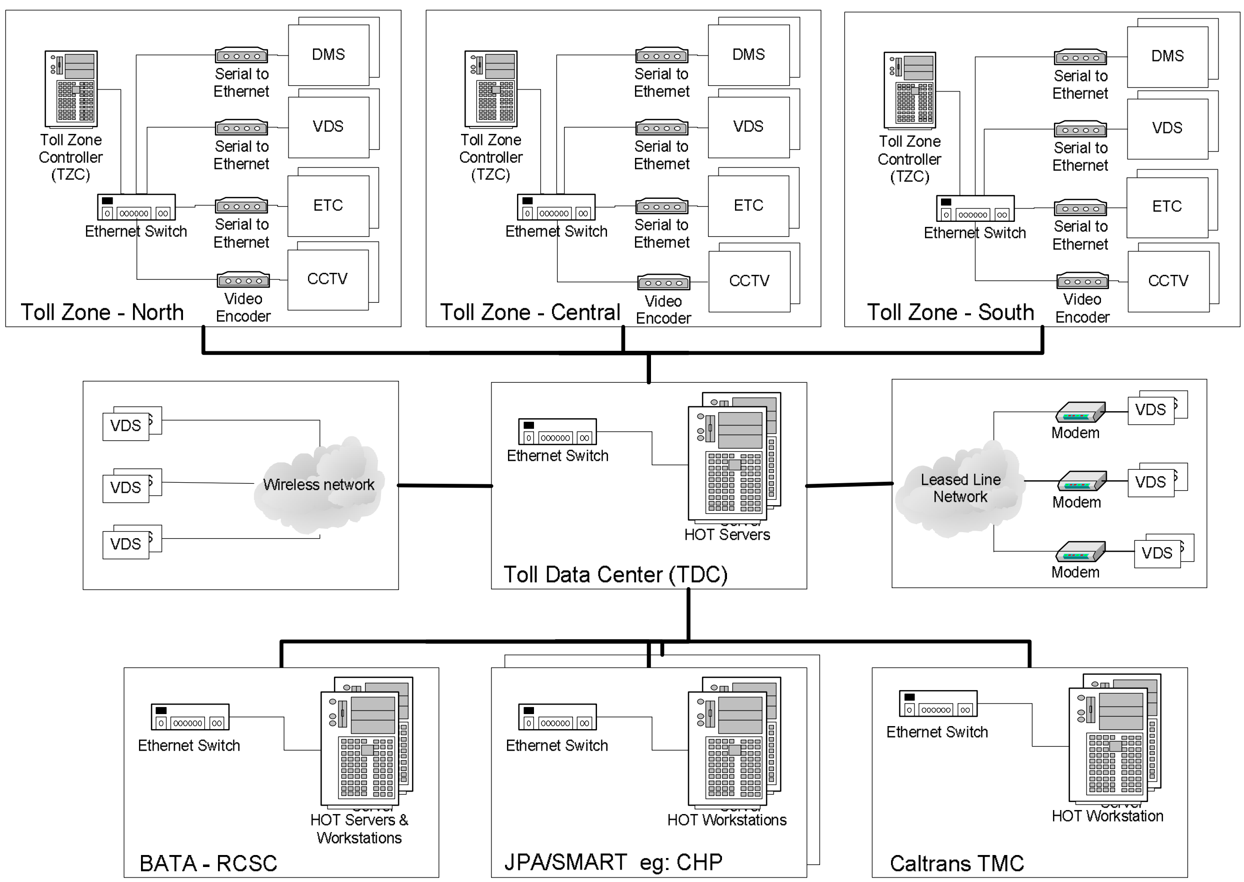


Figure 1 – Communication Node Connectivity

Each of the links identified in Figure 1, the Communication Node Connectivity block diagram, will contain performance requirements related to:

- Throughput;
- Capacity;
- Availability;
- Reliability;
- Security;
- Flexibility; and
- Maintainability.

2.1.1 Tolling Zone Subsystem Nodes

The Tolling Zone subsystem nodes will manage communications to all physical and electronic components at their designated location as well as other devices along the corridor in the vicinity of the Tolling Zone that are required to satisfy the functional capabilities of the Smart Lane system, including the Dynamic Message Signs (DMSs), Traffic Monitoring Stations (VDSs) and standard freeway traffic and tolling zone monitoring cameras, if required, at each tolling zone for security and observation purposes.

The field devices would include, as a minimum:

- Tolling Zone Controllers;
- ETC Readers;
- ETC Antennas;
- Dynamic Message Signs;
- Vehicle Detection Stations that are located in proximity to the tolling zone; and
- Closed Circuit TV (CCTV) Cameras for tolling zone and traffic monitoring.

2.1.2 Remote Vehicle Detection Stations

Those VDSs that are not located in proximity to the tolling zone will be connected to the TDC either by wide area wireless network or by 56K leased line modem connections. This is the type of connection currently in use by Caltrans for the majority of its VDSs within the Bay Area. Specifically, the proposed mixed flow lane VDS stations may be connected directly to the TDC via a wide area broadband wireless network.

2.1.3 Toll Data Center Node

The Toll Data Center node will manage all local communications to:

- trip transaction processors;
- all tolling zone equipment monitoring and control functions;
- transaction validation database;
- receipt, processing and distribution of FasTrak tag files;
- tolling zone communication processors;
- ETS support and maintenance functions;

- dynamic pricing module;
- revenue transaction/reconciliation processors;
- transaction database system (replication of TDC database); and
- Smart Customer Service Representatives (CSR) workstations.

2.1.4 Caltrans TMC Node

The Caltrans TMC node would be utilized for the transmission of I-680 operational status messages to and from the TDC and the Caltrans TMC. A typical message would be when TMC staff determines that, due to a reported problem in the Smart or mixed-use lanes, the Smart lane needs to be either closed or opened in a free mode until the reported problem is effectively resolved.

Additionally, count data from existing Caltrans VDSs in the mixed-use lanes will be shared with the TDC for the validation or backup of HOT lane VDSs. Existing Caltrans VDSs located in the HOT lanes may not be used operationally by the TDC for ETS VDS counts.

2.1.5 BATA RCSC Node

The BATA RCSC node will manage the TDC to BATA communications for:

- FasTrak customer account database system;
- CSR workstations;
- Transponder management subsystems; and
- Revenue collection subsystems.

2.1.6 JPA/Smart Lane User Information Node(s)

The JPA/Smart Lane user information link will communicate to a secure wide area network and provide pertinent data between the TDC and any other system that requires an interface to the TDC in order to obtain Smart Lane operating and/or auditing data. The California Highway Patrol (CHP), Valley Transportation Authority (VTA) and the MTC are examples of JPA/Smart users.

2.2 External Device Control (EDC) / Override System

The External Device Control (EDC) subsystem consists of:

- Remote monitoring of field devices which includes both the health of the hardware and the provisioning and maintenance of the software;
- Remote control/override of all roadside equipment related to safety; and
- Monitoring of Caltrans CCTV camera feeds, if available.

2.3 PERFORMANCE REQUIREMENTS

We have identified the following performance requirements as criteria for analysis and selection of the optimum communication networks and equipment.

2.3.1 Operating Environment

The equipment must be suitably hardened to operate under all conditions experienced in the San Francisco Bay Area. The temperature, humidity and air quality inside field cabinets are not suitable for office grade type equipment. In the interest of long-term system performance, only field-hardened equipment will be considered.

2.3.2 Redundancy

The ability to support communication path redundancy is important and is recommended for implementation on this project. Equipment redundancy (redundancy cards, power supplies, etc.) is related to mean time between failures (MTBF) of the equipment and will be considered during detailed design.

2.3.3 Topology

Network topology is defined as the physical arrangement of nodes and interconnecting communications links within the network. Typical topologies include bus, star, ring, and mesh. Some topologies are better suited than others for providing path redundancy. Given the geographical configuration of the communication nodes required for this project, ring and star type topologies are the only architectures that will be considered.

2.3.4 Throughput

The throughput requirements, which can be defined as the amount of data that can be passed across a communications link in a given period of time, are primarily a function of the Smart Lane transaction and CCTV data load. The communications infrastructure will be capable of handling Smart Lane transactions during peak periods coincident with the many other data movement activities.

In order to determine the throughput requirements associated with the tolling transactions, the figures generated from the HOV 3+ modeling for Year 2025 were used.

Paying HOT Lane Vehicles (Peak Hour):	828	(max. value for all zones)
Assumed DSRC transaction record size:	520 bytes	
Contingency Factor:	1.5x	
Peak hour data throughput:	645,840 bytes/hour	
or:	1435bps	

Based solely on transaction data throughput, there is not a significant requirement for throughput on the communications link from the Tolling Zones to the Tolling Data Center.

The primary throughput requirement for these links will be for the video feeds from the CCTV cameras located within Tolling Zone. The data speed requirement for compressed digitized video is a factor of both the image size (pixels) and the frame rate. The following table provides a summary of the typical data rates for various image sizes and frames rates. Full motion video is 30 frames per second (fps).

Standard image sizes are as follows:

360x240	CIF (Common Intermediate Format)
720x240	2CIF
720x480	4CIF

Data Rate	Image Size	Frame Rates
384kbps	CIF 2CIF 4CIF	7.5 – 10 fps 5 – 6 fps 2 – 3 fps
768kbps	CIF 2CIF 4CIF	15 – 20 fps 10 – 15 fps 5 – 6 fps
1.5Mbps	CIF 2CIF 4CIF	30 fps 25 fps 10 – 15 fps

It is recommended that at a minimum, a 1.5Mbps throughput be used to achieve a 4CIF image at 10 – 15 fps.

2.3.5 Capacity

The communications infrastructure will be capable of providing not only sufficient capacity to meet the current data throughput needs but shall have sufficient capacity for the anticipated growth in the quantity of transactions and the possibility of servicing, as a minimum, a northbound I-680 Smart Lane.

2.3.6 Availability

In order to provide accurate tracking of the traffic flow and timely and accurate toll adjustments in response to traffic flow variations, the selection of the system components and the design of the infrastructure will ensure that availability is a key requirement for the Smart Lane Project. Availability is defined as the percentage of network or system uptime versus total time. Typical values for high availability communication systems are from 99.99% up to 99.999%. This corresponds to a total unscheduled downtime of 52 minutes/year and 5.2 minutes/year, respectively.

In addition, the Mean Time between Failure (MTBF) of the overall communications network will be under 4 hours to minimize data loss and operational impact. The communications managed services that would be provided by Communications Service Providers will be required to meet or exceed the maximum MTBF acceptable by the I-680 Smart Lane ETS.

2.3.7 Reliability

Acceptable values for MTBF of all communication system components will be determined.

2.3.8 Security

The Smart Lane communications system infrastructure will be protected against physical damage, destruction, theft or replacement of hardware. Data security will be ensured through the design and utilization of secure communication protocols.

2.3.9 Flexibility

The communications infrastructure design will ensure that future communication network enhancements to the Smart Lane project, such as the addition of more tolling zones or VDSs if and when required, can be easily and quickly implemented.

2.3.10 Maintainability

Ease of maintenance is important to be effectively designed into the Smart Lane Project. The ability to easily configure the hardware and plug-and-play replacement of components in the field is an important consideration.

2.3.11 Interoperability

The ability to use different vendor equipment in the same network is important in order to maintain competitive pricing and for future-proofing of the communication networks that is deployed. The standardization of the protocols should, at least theoretically, allow interoperability. Second source availability of communication network equipment and components will also be required.

3. DESIGN ASSUMPTIONS

In order to proceed with the development of the preliminary communications architecture for the I-680 Smart Lane system, prior to the completion of the overall system design, it is necessary to make a number of assumptions about the existing communications infrastructure along the corridor and from the corridor to the TDC, which will be located in Oakland. As the project progresses, the communication system design assumptions will be revisited and any changes will be clearly conveyed to the ACCMA.

3.1 EXISTING INFRASTRUCTURE

Based upon discussions with Caltrans staff, it has been determined that there is no existing or near-term planned Caltrans communications infrastructure available along the I-680 corridor within the limits of this project which could be used for communication between the tolling zones, the traffic monitoring systems, the dynamic message signs and the TDC. In addition, it is has been determined that there is no existing communications infrastructure available for the Smart Lane project from any of the project partner agencies along the corridor that could provide suitable connectivity from the three tolling zones to the TDC.

3.2 TOLLING ZONE TO TDC COMMUNICATIONS

Due to the distances between the Tolling Zones and the TDC (up to 26 miles) and the relatively high costs associated with adding new underground infrastructure, the communication links between the Tolling Zones and the TDC will utilize either leased data communication services or a wireless communication network solution.

3.3 VEHICLE DETECTION STATIONS

Based upon discussions with Caltrans staff, the existing Caltrans traffic monitoring stations (in the ITS industry these stations are referred to as VDSs) will maintain their direct leased line communications link to the Caltrans TMC. If it is determined that the data collected from these Caltrans traffic monitoring stations will be utilized by the Smart Lane system to calculate travel time in the mixed flow lanes, this data would be sent to the TDC via the communications link that will be established between the TMC and TDC. It is assumed that any VDSs implemented as part of the I-680 Smart Lane Project and installed outside of the Tolling Zone areas would be standalone and will utilize both wide area wireless mode and, where appropriate, the same leased line communication mode that Caltrans has in operation. New VDS equipment that is located within 500 feet from one of the tolling zones may communicate to the TDC via the tolling zone to TDC communications link.

3.4 WIRELESS COMMUNICATION LINKS

For any locations where it is proposed to use wireless communications, either between field devices or from the corridor to the TDC, it is believed that clear line of sight is available between the end points of the link or through suitable intermediate repeater location(s). However, the ETS Contractor shall be required to conduct a comprehensive analysis to determine whether a wireless link can be deployed at these locations. Subsequent site surveys and spectrum surveys may determine that a wireless solution is not suitable due to topography, geography or obstacles and a re-evaluation of the communications architecture for that link might be required.

In addition, service provider based wide area wireless links may be appropriate to communicate to the proposed mixed flow lane VDS stations along the corridor.

4. NETWORK ARCHITECTURE ALTERNATIVES

Based on the physical locations, both Ring and Star topologies were evaluated.

4.1 PRIMARY NODES PHYSICAL LOCATION

The first step in the development of the design for the communications network for the I-680 Smart Lane is to geographically locate the primary nodes within the network and determine the most suitable method of interconnection of those nodes based upon the requirements of the flow of data as well as any geographical or physical constraints that may dictate alternative communication paths. Figure 2 provides the physical address of each facility that is known or, in the case of the three Tolling Zones, a selected address on a frontage street adjacent to the southbound lanes at the anticipated location of the Tolling Zone Controller (TZC).

Node Locations	Address
North Tolling Zone	6901 Mission Rd. Sunol, CA 94586 (approx. address)
Central Tolling Zone	1901 Jackson Ct. Fremont, CA 94539 (approx. address)
South Tolling Zone	45958 Research Ave. Fremont, CA 94539 (approx. address)
Caltrans District 4	111 Grand Ave. Oakland, CA 94623
Bay Area Tolling Authority (BATA)	Embarcadero San Francisco, CA
Toll Data Center (ACCMA)	1333 Broadway, Suite 220 Oakland, CA 94612

Figure 2 – Facility Addresses

Figure 3 shows the geographical locations of these communication nodes.

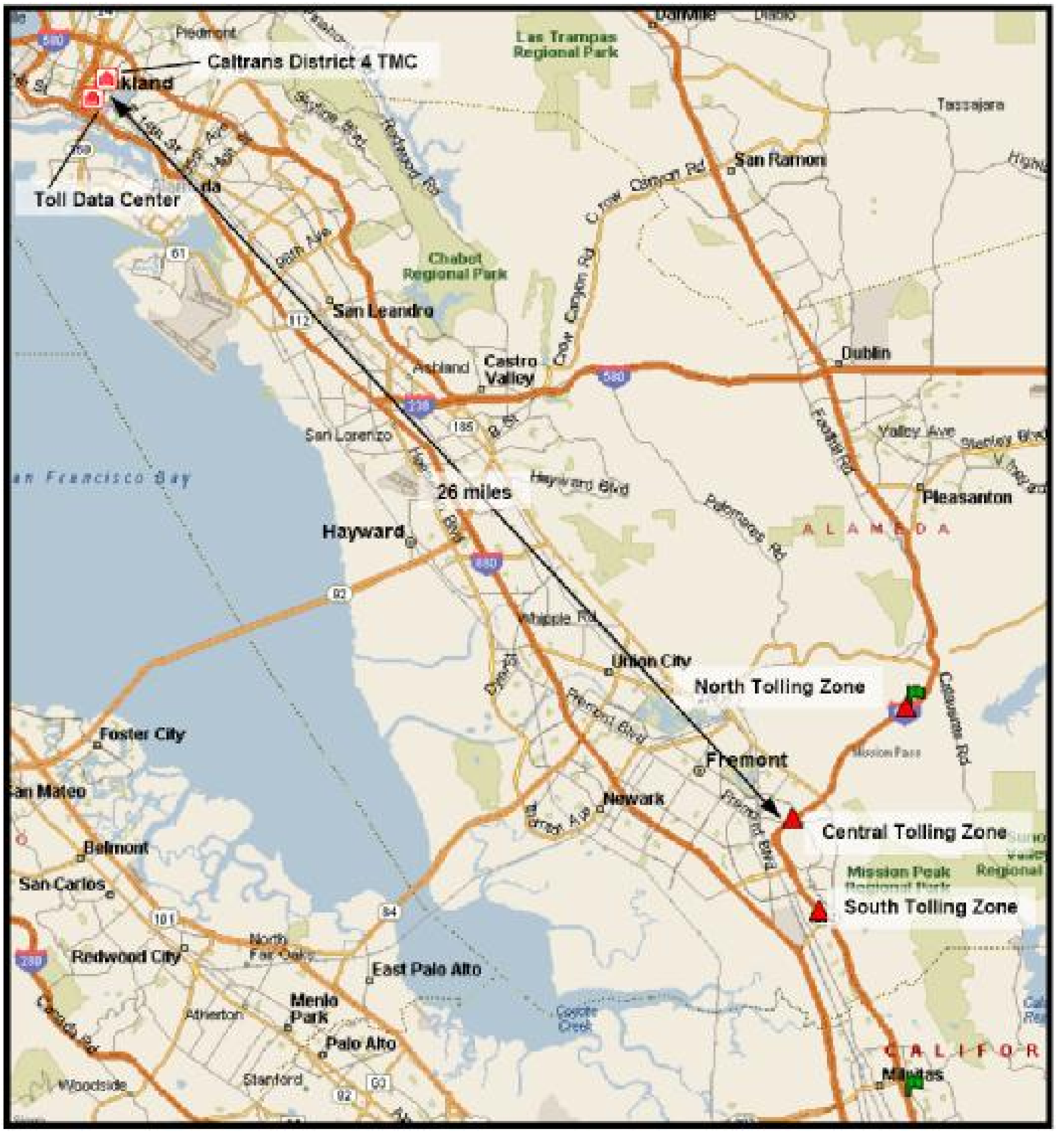


Figure 3 - Facility Locations

4.2 Ring Topology

In a ring topology the Toll Zones and TDC nodes are interconnected serially in a circle or ring as shown in Figure 4. All communication between the nodes of the network passes around the ring from node to node. In many cases a network set up with a ring topology is configured to take advantage of the fact that there are two paths between any two nodes. Should there be a failure in a path or a node the ring can "self heal" in that communication can be rerouted in the opposite direction around the ring. This added robustness and flexibility in the architecture are beneficial from a technological standpoint, but it is usually associated with higher costs for the node equipment.

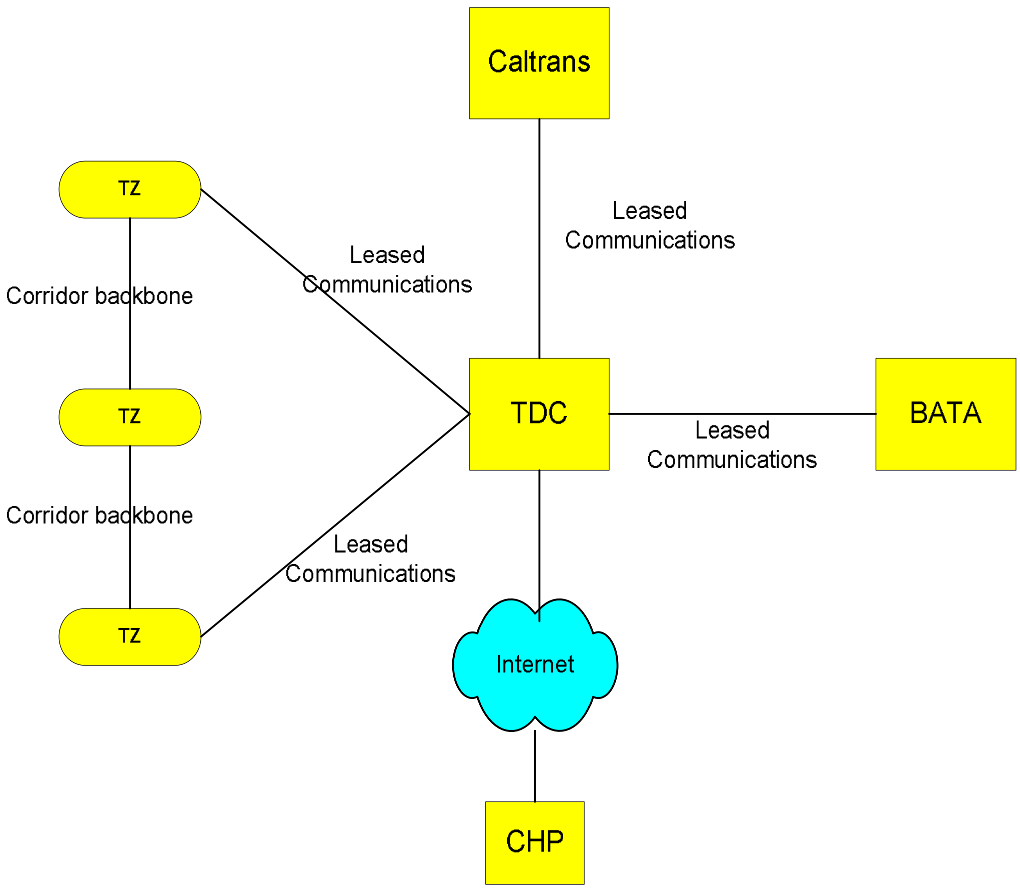


Figure 4 - Ring Topology

4.3 STAR TOPOLOGY

With a star topology the communication paths connect the Toll Zone nodes to a central node or hub as shown in Figure 5. Any communication between nodes must pass through the hub. Although this architecture is easily expandable, easier to monitor and maintain but is more susceptible to outage since a failure at the hub cuts off communication between all nodes.

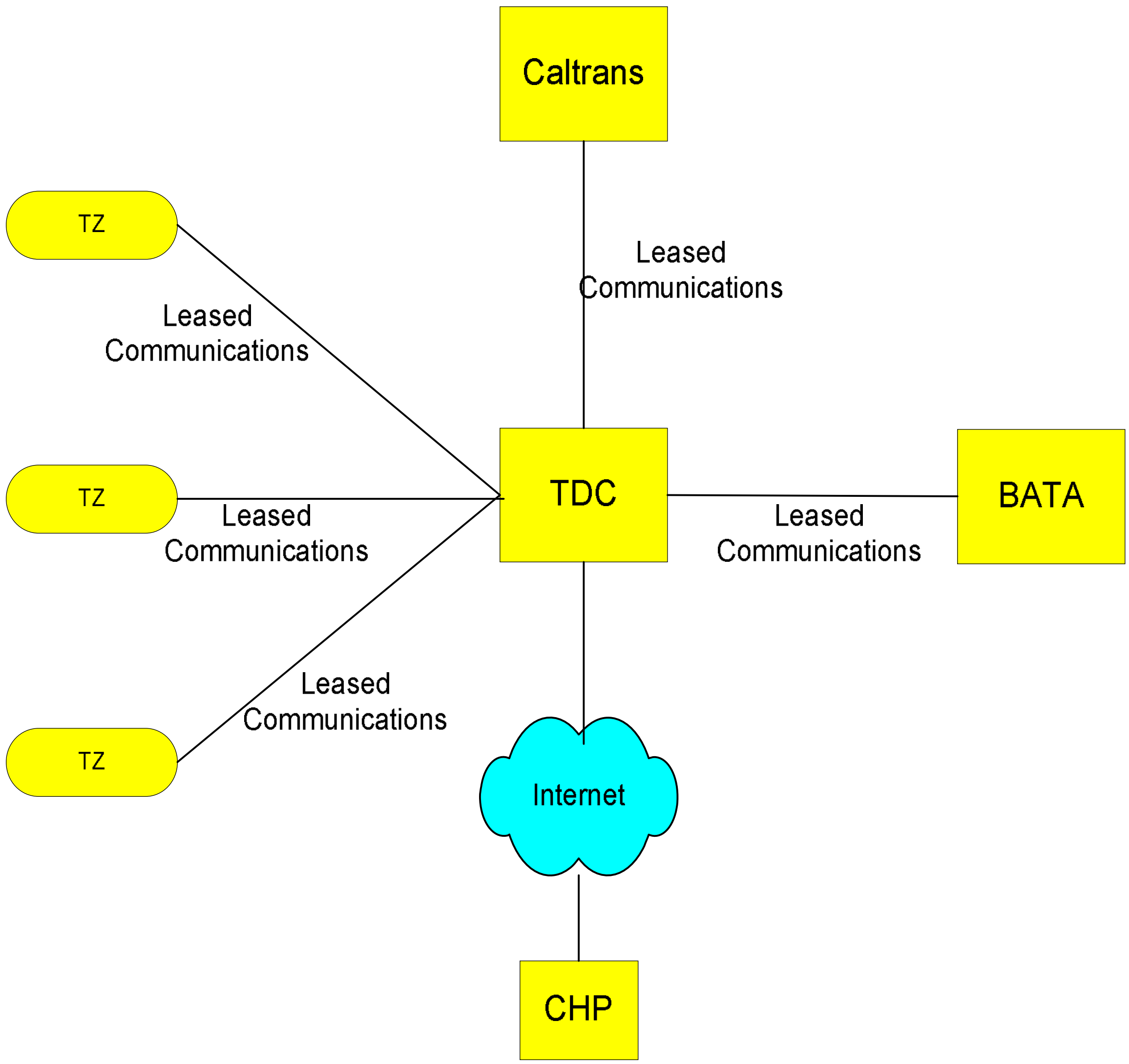


Figure 5 - Star Topology

4.4 COMMUNICATIONS SYSTEM ANALYSIS

In order to determine the best suited topology for the I-680 Smart Lane project, the advantages and disadvantages of the ring and star configurations described in the previous section was reviewed based on the criteria identified in Section 2.3.

The results of the review have led to the following architecture recommendations.

The high level of network reliability necessary to maintain the real-time monitoring of traffic flow and the collection of toll information can be achieved in a cost-effective manner by implementing a hybrid of the ring and star configurations. Figure 6 shows each of the Tolling Zones with a dedicated primary communications path to the TDC using leased line communications.

In addition to this primary path it is recommended that the architecture include secondary or redundant communications paths between the Tolling Zones. These paths would provide a failover or redundant route for communications back to the TDC if a problem was experienced by one of the links. Since these paths are not a primary communications path under normal operating conditions, as would be the case under a traditional ring architecture, these paths can be implemented using more cost-effective technology, such as wireless, or possibly a lower data rate point-to-point leased line connection. The selection of the communications technology for these redundant paths will be discussed in the following section. It should be noted that the path redundancy referred to is for node-to-node communications only and does not include the ETC VDS installations.

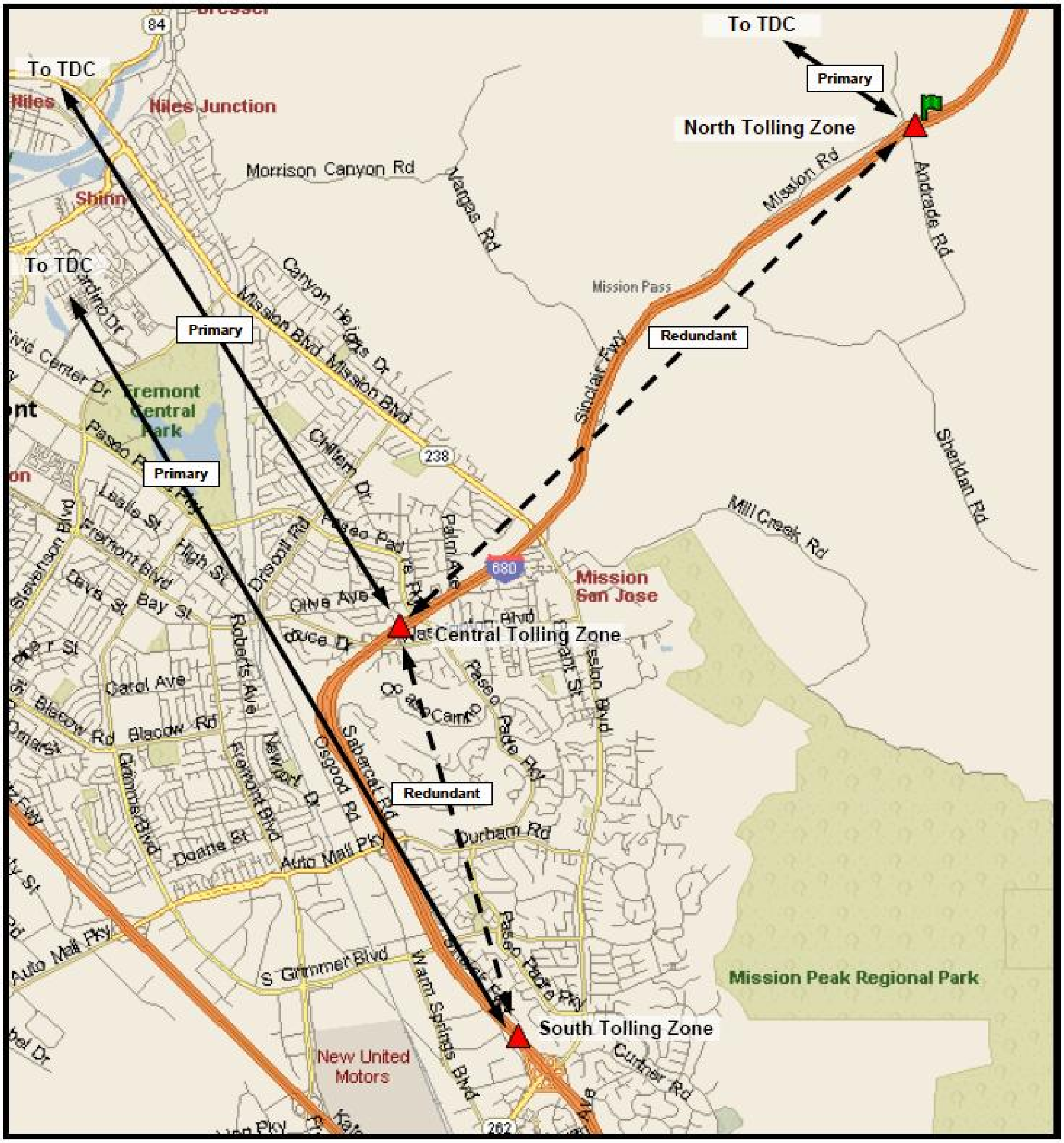


Figure 6 - Primary and Redundant Communication Paths

5. COMMUNICATION TECHNOLOGIES

5.1 COMMUNICATION TECHNOLOGIES OVERVIEW

The proposed Smart Lane application for the I-680 southbound corridor consists of ETS components and VDSs in the field, central and back office components which need to communicate via a reliable, secure and highly available communications network. A network of communications nodes connected via a physical communications medium and a suite of logical network layer technologies would achieve this capability.

The physical communication options available are:

- Wired communications; and
- Wireless communications.

5.2 WIRED COMMUNICATIONS

The typical wired communications available are in:

- Managed data services as point-to-point (P2P) (using local Service Providers);
- Fiber network (privately installed and maintained); and
- Twisted pair/coax (privately installed and maintained).

5.2.1 Managed Data Services

There are several managed data transport services available from the Tier 1 service providers, such as Sprint, AT&T, SBC and Verizon, which can satisfy the communication system requirements of both the tolling zone to TDC and the back office interconnection networks. The available technologies include:

- Frame Relay;
- Multi-Protocol Label Switching (MPLS); and
- T1 Lines.

5.2.1.1 Frame Relay

Frame relay is a telecommunication service designed for cost-efficient data transmission for intermittent traffic between local area networks (LANs) and between end-points in a wide area network (WAN). Frame relay is based on the older X.25 packet-switching technology which was designed for transmitting analog data such as voice conversations. Unlike X.25, which was designed for analog signals, frame relay is a fast-packet technology, which means that the protocol does not attempt to correct errors. When an error is detected in a frame, it is simply "dropped". The end points are responsible for detecting and re-transmitting “dropped” frames. Frame relay service is available at data rates starting at 128kbps up to DS3 (45Mbps).

Advantages of a frame relay:

- Secure and reliable; and
- Scalable bandwidth.

Disadvantages of a frame relay:

- Dated Technology;
- Designed for non continuous data management; and
- Higher overhead on retransmission.

5.2.1.2 Multi-Protocol Label Switching (MPLS)

Multi-Protocol Label Switching is a method used to increase the speed of network traffic flow by inserting information about a specific path the packet is taking en route to its destination. This saves the time needed for a router to look up the address for the next node that the packet is supposed to be sent to. MPLS is multi-protocol in that it works with IP, ATM, and Frame Relay communications methods. In addition, MPLS has some quality of service features that make it an attractive communications technique for connecting LANs and between end-points in a WAN configuration.

Advantages of MPLS:

- Secure and reliable; and
- Available quality of Service.

Disadvantages of MPLS:

- Cost; and
- Higher overhead on retransmission.

5.2.1.3 T1 Lines

A T1 is a dedicated data connection supporting rates of 1.544Mbits per second. A T1 line actually consists of 24 individual channels, each of which supports 64Kbits per second. Each 64Kbit/second channel can be configured to carry voice or data traffic.

Advantages of T1:

- Secure;
- Reliable; and
- High availability.

Disadvantages of a frame relay:

- Dated Technology; and
- Designed for non-voice and data.

5.2.2 Fiber Optic

Fiber optic based communications systems offer the best quality of service available on the market. Ethernet protocols over fiber cable have proved to be the technology of choice for data communications in tolling and Intelligent Transportation System (ITS) applications. Fiber optics is a very stable, dynamically scalable technology that allows for maximum bandwidth utilization for today's congested networks.

Media	Technology	Standard	Max. Transfer Rate
Two optical fibers	100Base-FX	IEEE 802.3u	100 Mbps
Two multi-mode or single-mode optical fibers (long wave)	1000Base-LX	IEEE 802.3z	1 Gbps
Two multi-mode optical fibers (shortwave)	1000Base-SX	IEEE 802.3z	1 Gbps

Advantages of a fiber optic network:

- Secure and reliable;
- Large bandwidth;
- Available capacity for future use;
- Allows for easier interconnection of multi-vendor equipment;
- Uses standard industry open protocols; and
- Reduces recurring costs.

Disadvantages of a fiber optic network:

- High initial capital cost of the equipment;
- High installation costs; and
- Requires wired connections between the tolling zones.

5.2.3 Twisted Pair/Coax

The twisted-pair/coax technology is based upon the same lower cost copper twisted-pair wiring used in telephone systems. With its reliance on proven telephone system technology, the twisted-pair variety of Ethernet provides a reliable, yet simple and relatively low-cost method for connecting devices.

Media	Technology	Standard	Max. Transfer Rate
CAT5 cable	100Base-TX	IEEE 802.3u	100 Mbps
CAT5e cable	1000Base-T	IEEE 802.3ab	1 Gbps

Advantages of the twisted pair/coax approach:

- Lower cost solution;
- Large bandwidth;
- Easy to work with;
- Allows for easier interconnection of multi-vendor equipment;
- Uses standard industry open protocols; and
- Reduces recurring costs.

Disadvantages of the twisted pair/coax approach:

- Susceptible to interference and noise; and
- Short-range operations (<5000ft).

5.3 WIRELESS

Wireless communications technologies are available in:

- Broadband Wide Area Network (WAN) wireless configuration; and
- Fixed wireless configuration.

5.3.1 Broadband WAN Wireless

Broadband wireless communications with WiMAX and 3G technologies provide high-throughput connections over long distances.

The following are considered WAN Wireless technologies.

Technology	Standard	Max. Transfer Rate	Range	Frequency
Wi-Fi	802.11a	54 Mbps	300 ft	5 GHz
Wi-Fi	802.11b	11 Mbps	300 ft	2.4 GHz
Wi-Fi	802.11g	54 Mbps	300 ft	2.4 GHz
WiMAX	802.16d	75 Mbps	4-6 miles	11GHz
WiMAX	802.16e	30 Mbps	1-3 miles	2-6GHz
CDMA2000/ 1xEV-DO	3G	2.4Mbps	1-5 miles	400, 800, 900, 1700, 1800, 1900, 2100 MHz
WCDMA/ UTMS HSDPA	3G	2Mbps	1-5 miles	1800, 1900, 2100 MHz

Three Broadband WAN Wireless technologies were evaluated:

- Wireless Fidelity (Wi-Fi);
- WiMAX; and
- Wireless 3G.

5.3.1.1 Wireless Fidelity (Wi-Fi)

A wireless local area network (WLAN) uses radio frequency (RF) technology to transmit and receive data over the air. IEEE has established the IEEE 802.11 standard, which is the predominant standard for wireless LANs. Interoperability with wired infrastructure is generally not an issue because most WLAN systems provide industry standard interconnections to Ethernet (802.3) and Token Ring (802.5). Any LAN application, network operating system, or protocol, including TCP/IP, will run on 802.11-compliant WLANs as they would over Ethernet. Wi-Fi technologies include the approved IEEE 802.11a, b and g specifications.

Specification	802.11b	802.11g	802.11a
Outdoor Range (Line of Sight)	400 ft (120 m) @ 11 Mbps; 1500 ft (460 m) @ 1 Mbps	400 ft (120 m) @ 54 Mbps; 1500 ft (460 m) @ 1 Mbps	100 ft (30m) @ 54 Mbps; 1000 ft (305m) @ 6 Mbps
Data Rates	11, 5.5, 2 and 1 Mbps	54, 48, 36, 24, 18, 12, 9, and 6 Mbps	54, 48, 36, 24, 18, 12, 8, and 6 Mbps
Wireless Medium	Direct Sequence Spread (DSSS), 2.4 GHz	Orthogonal Frequency Division Multiplexing (OFDM), 2.4 GHz	Orthogonal Frequency Division Multiplexing (OFDM), 5 GHz

Advantages of a Wi-Fi approach:

- Low initial cost for equipment and infrastructure;
- Low maintenance cost;
- Not affected by weather conditions;
- Secure network;
- Easily reconfigured and expanded; and
- Interoperability with wired infrastructure systems.

Disadvantages of a Wi-Fi approach:

- Uses unlicensed spectrum, therefore there is the potential for interference;
- Usually requires line-of-sight or the installation of a repeater site; and
- The technology has limited operating range (~300 feet).

5.3.1.2 WiMAX

An implementation of the IEEE 802.16 standard, WiMAX is a wireless metropolitan area network technology that can provide broadband access to areas where wired connections are unsuitable or unfeasible. WiMAX systems can be used to transmit signal as far as 30 miles at speeds of up to 75 Mb/sec although the actual over-the-air data rates are slightly less. Coverage and data rates are primarily a function of the antenna height, antenna gain, the terrain and line-of-sight between endpoints.

WiMAX also supports mesh networking, so transmissions can travel longer distances by "hopping" across a number of access point locations in a metropolitan area.

Technology	Standard	Max. Transfer Rate	Range	Frequency
WiMAX	802.16d	75 Mbps	4-6 miles	11GHz
WiMAX	802.16e	30 Mbps	1-3 miles	2-6GHz

Advantages of the WiMAX approach:

- Low initial cost for equipment and infrastructure;
- Low maintenance cost;
- Not affected by weather conditions;
- Secure network; and
- Easily reconfigured and expanded.

Disadvantages of the WiMAX approach:

- Uses an unlicensed spectrum so there is a potential for interference; and
- Usually requires line-of-sight (LOS) or the installation of a repeater site.

5.3.1.3 Wireless 3G

Wireless 3G is an International Telecommunication Union (ITU) specification for high-speed wireless communications. This worldwide wireless connection is compatible with GSM, TDMA, and CDMA. Next-generation 3G cellular services will create broad-range coverage for data access across wide geographic areas. The 3G standard will include systems like CDMA2000, UMTS, GPRS, EDGE, HSDPA, EV-DO and WCDMA.

Technology	Standard	Max. Transfer Rate	Range	Frequency
CDMA2000/ 1xEV-DO	3G	2.4Mbps	1-5 miles	400, 800, 900, 1700, 1800, 1900, 2100 MHz
WCDMA/ UTMS HSDPA	3G	2Mbps	1-5 miles	1800, 1900, 2100 MHz

Advantages of the Wireless 3G approach:

- Use of packet-oriented networks based on IP;
- Not affected by weather conditions;
- Secure network; and
- Easily reconfigured and expanded.

Disadvantages of the Wireless 3G approach:

- Large bandwidth is relatively expensive; and
- Coverage is currently limited.

5.3.2 Fixed Wireless

Fixed Wireless is a method for provisioning a network segment between two fixed locations using wireless devices or systems. Most fixed wireless systems rely on digital radio transmitters placed on rooftops, aerial towers, or other elevated structures and achieve point-to-point or point-to-multipoint signal transmission via a microwave communications platform. Fixed wireless is increasingly used as a fast and economic way to roll out high-speed data services since it avoids the need for fixed wires or fiber optics cable.

5.4 LOGICAL NETWORK LAYER OPTIONS

For the purposes of the I-680 Smart Lane project, the following Ethernet technology standards were considered as part of the evaluation.

Technology	Standard	Max. Transfer Rate	Media
100Base-TX	IEEE 802.3u	100 Mbps	CAT5 cable
100Base-FX	IEEE 802.3u	100 Mbps	Two optical fibers
1000Base-T	IEEE 802.3ab	1 Gbps	CAT5e cable
1000Base-LX	IEEE 802.3z	1 Gbps	Two multimode or single-mode optical fibers (long wave)
1000Base-SX	IEEE 802.3z	1 Gbps	Two multimode optical fibers (shortwave)

6. NETWORK SEGMENT ALTERNATIVES

This section identifies the possible application of above identified technologies to the Communications segments within the I-680 Smart lane environment

6.1 TOLLING ZONE TO TDC COMMUNICATIONS (PRIMARY CONNECTIONS)

6.1.1 Alternatives

The network communication technologies solution between Tolling Zones and TDC shall based upon physical network layout requirements, availability, cost of implementation and performance requirements.

The possible tolling zone network options are:

- Managed services;
- WiMAX;
- Fiber; and
- Shared fiber.

6.1.2 Analysis

In order to determine the best-suited technology for the primary Tolling Zone to TDC communication, the advantages and disadvantages of the managed services, wireless (WiMAX), fiber and shared fiber technologies must be weighed against the system requirements, technology reliability and the initial cost of implementation.

6.2 TDC TO TRAFFIC MANAGEMENT CENTER AND TDC TO BATA COMMUNICATIONS

6.2.1 Alternatives

The network communication options between the TDC and Caltran's TMC and from the TDC to BATA shall be based upon availability of existing Communications infrastructure, cost of implementation and performance requirements.

The possible tolling zone network options are:

- Managed Services; and
- Fiber.

6.2.2 Analysis

In order to determine the best-suited technology for the TDC to TMC and the TDC to BATA communication, the advantages and disadvantages of the managed services and fiber must be weighed against the performance requirements, availability and the initial cost of implementation.

6.3 TDC TO OTHER JPA AGENCIES AND CHP COMMUNICATIONS

6.3.1 Alternatives

The network communication options between the TDC and other JPA agencies and CHP shall be based upon availability of existing communications infrastructure, cost of implementation and performance requirements.

The possible tolling zone network options are:

- Managed Services; and
- Secure Internet connections.

6.3.2 Analysis

In order to determine the best-suited technology for the TDC to other JPA agencies and CHP communications, the advantages and disadvantages of the managed services and secure internet connections must be weighed against the performance requirements, availability and the initial cost of implementation.

6.4 TOLLING ZONE TO TOLLING ZONE (REDUNDANT CONNECTIONS)

6.4.1 Alternatives

The redundant network communication technologies between Tolling Zones are based upon physical network layout, system and performance requirements.

The possible tolling zone network options are:

- WiMAX;
- Fixed Wireless; and
- Fiber.

6.4.2 Analysis

In order to determine the best-suited technology for the redundant Tolling Zone to Tolling Zone communications, the advantages and disadvantages of the wireless (WiMAX), fixed wireless and fiber technologies must be weighed against the system requirements, technology reliability and the initial cost of implementation.

6.5 INTRA -TOLLING ZONE COMMUNICATIONS

6.5.1 Alternatives

The communication technologies that were considered at the Tolling Zones were based on physical network layout, system configuration and performance requirements. The three Tolling Zone sites will be equipped with a tolling zone controller (TZC) to manage the communications between subsystems and the TDC, the Dynamic Message Signs (DMS) used to display the current toll rate, the ETC readers, ETC antennas that are used to detect transponders in the Smart Lane and vehicle detector stations that will monitor traffic in the Smart Lane.

The TZC will consist of two independent computers (for redundancy) equipped with Ethernet network cards for interfacing with the communications system. The DMS controllers are typically connected via serial communications. In order to interface with the communications system, an Ethernet-to-serial converter would be required. The ETC readers are typically connected via serial communications, and therefore, they would require the use of an Ethernet-to-serial converter. The VDSs are typically connected via serial communications. In order to interface with the communications system, an Ethernet-to-serial converter would be required for this equipment.

The possible Intra-Tolling Zone communication options are:

- Fiber optics;
- Twisted Pair; and
- Wi-Fi.

6.5.2 Analysis

In order to determine the best-suited technology for Intra-Tolling Zone communications, the advantages and disadvantages of the fiber, twisted pair and wireless technologies (Wi-Fi) must be weighed against the system requirements, technology, security, reliability and the initial cost of implementation. This analysis is summarized in Section 7.

6.6 HOT LANE INFORMATION COMMUNICATION

6.6.1 Alternatives

Define Smart Lane Information Communication requirements for:

- Back-office;
- Customer service; and
- Customer web access.

Identify performance requirements for:

- Availability;
- Security;
- Reliability;

- Redundancy; and
- Operational costs.

Options include:

- Private leased network (frame relay) interconnecting sites; or
- VPN over the Internet.

6.6.2 Analysis

In order to determine the best-suited technology for Smart Lane information communication, the advantages and disadvantages of the leased, VPN and wireless technologies must be weighed against the system requirements, technology reliability and the initial cost of implementation. This analysis is summarized in Section 7.

6.7 NODE COMMUNICATIONS SUMMARY

Presented below is a summary of the available technologies that could be deployed for communications between:

- Tolling Zone Subsystem Nodes;
- Toll Data Center Node;
- Caltrans TMC Node;
- BATA RCSC/Revenue Management system Node; and
- Smart Information Network Nodes for the JPA.

Physical Link	Technology Options	Available Service Provider
TDC <-> TMC	Frame Relay	Sprint, AT&T, SBC, Verizon
TDC <-> BATA	Frame Relay	Sprint, AT&T, SBC, Verizon
TDC <-> JPA	Frame Relay, VPN	Sprint, AT&T, SBC, Verizon
TDC <-> TZ's	Frame Relay, Fixed Wireless, WiMAX, Fiber	Sprint, AT&T, SBC, Verizon, NextWeb, 1stUniverse
TZ <-> TZ	Frame Relay, Fixed Wireless, WiMAX, Fiber	Sprint, AT&T, SBC, Verizon, NextWeb, 1stUniverse
@ TZ's	Fiber, Twisted Pair, Wi-Fi	TBD

6.8 SERVICE LEVEL WARRANTIES FOR MANAGED SERVICES

As part of the terms and conditions of the contract for managed data services with any of the Tier 1 service providers there will be a warranty, or Service Level Agreement (SLA), on the performance of the service typically based on the following parameters:

- **Availability –** expressed as a percentage of the time service is available;
- **Latency –** average round-trip transmission time between customer endpoints; and
- **Packet Loss –** maximum quantity of packet loss averaged over a month and expressed as a percentage.

Should the service provider not meet these performance parameters they will provide a prorated service credit for the portion of the time the SLA parameters during any billing period. The SLA would not apply to situations such as an Act of God (force majeure), scheduled network maintenance or the actions or inactions of the customer or any third parties.

Contract terms and conditions usually state that there will be known periods of network outage as required for maintenance. If the JPA is to be affected, they would be notified several days in advance of the timeframe and duration of the scheduled outage. These scheduled maintenance outages are typically confined to small geographical areas so the likelihood of a scheduled outage affecting more than one Tolling Zone site would be very small.

Although it is known that there will be planned and unplanned outages of the leased communications between the TDC and the three Tolling Zones, it is possible to reduce this risk by providing hot fail-over redundant communications paths between the nodes on the network and utilize Border Gateway Protocol (BGP) between the routers at each node.

Border Gateway Protocol is a dynamic routing protocol used between two or more autonomous systems to exchange routing information and network availability. This information can then be used to identify which path is the most efficient for each data packet, and then route the packet to its destination on the fastest path. Should the primary communications path fail the data would automatically be routed to the secondary path.

7. ANALYSIS

7.1 TOLLING ZONE TO TDC COMMUNICATIONS (PRIMARY CONNECTIONS)

Technology Options	Advantages	Disadvantages	Capital Cost	Operating Cost
Managed Services Frame Relay	• Service available at all sites from multiple providers • Scalable bandwidth as needs change • Reliable • High availability (99.999%)	• Ongoing operation costs are high and are usually locked into multi-year contracts	Network Equipment and Installation Cost: $3,500/site (3 sites) The TDC site is included in previous cost	Recurring monthly charges: Circuit: $500/site Maintenance/Monitoring: $200/site Total: $700/site/month for T1 data rates
			$10,500	$25,200/year
WiMAX	• High data rates and longer distances are achievable • Relatively low capital costs and no operational costs • Reliable • High availability (99.99%)	• Requires line-of-sight or near line-of-sight between Tolling zones and TDC • Excessively tall antenna structures potentially required • Environmental issues need to be addressed • More detailed analysis is required	Equipment and Installation Costs: >$30,000 per endpoint (hut, antenna structure, power, transmission equipment) (4 end points)	No recurring costs except for ongoing maintenance and support contracts and the stocking of spare components.
		Not viable at this stage	$120,000	$35,000/ (Maintenance and Spares for LOS required)
Fiber	• High reliability • Available bandwidth for future applications • Bandwidth can be shared with other services/	• Prohibitively expensive • Maintenance of over 24 miles of fiber not viable • Prone to damage due to elements, natural disasters	• Estimate based on similar projects: > $15 million	• Maintenance of fiber along highway is very expensive

Technology Options	Advantages	Disadvantages	Capital Cost	Operating Cost
	users			
			>$15,000,000	>$100K/year
Shared Fiber (Shared use of SV-ITS SONET network)	• Use of existing SV-ITS SONET network would provide a reliable and cost effective link from the South Tolling Zone to downtown Oakland	• Closest SONET node is located at the City of San Jose TMC • Link from South Tolling Zone to CSJ TMC would require an 11.3 mile wireless link • Line-of-Sight not available • Wireless link not recommended for primary communications link • Dependence on 3rd party owned equipment and sharing of communication networks • High risk in achieving integrity and required Level Of Service	• Cost for wireless equipment and installation: • High cost for link to CSJ TMC	• Ongoing maintenance and support.
		Not viable	Very expensive	

In evaluating the above options for communication solutions for the TDC to the Toll Zones links, Managed Services, specifically frame relay technology, is recommended primarily because it satisfies the performance requirements identified in Section 2.3 and also because of the relatively low initial capital costs. The construction of a new dedicated fiber link or the sharing of existing stakeholder agency fiber is cost prohibitive.

7.2 TDC to Traffic Management Center and TDC to BATA Communications

Technology Options	Advantages	Disadvantages	Capital Cost	Operating Cost
Managed Services Frame Relay	• Service available at all sites from multiple providers • Scalable	• Ongoing operation costs • Multi-year contracts usually	Network Equipment and Installation Cost: $3,500/site (3 sites)	Recurring monthly charges: Circuit: $500/site Maintenance/Monitoring: $200/site Total: $700/site/month for frame relay with T1 data

Technology Options	Advantages	Disadvantages	Capital Cost	Operating Cost
	bandwidth as needs change • Reliable • High availability (99.999%)	required from provider		rates
			$10,500	$25,200/year
Fiber	• Agency owned and maintained comm. infrastructure • Large bandwidth • Reliable • Secure	• Very high initial capital costs for equipment and construction in metropolitan area • Ongoing costs for maintenance	Estimate based on similar projects: > $2,500,000	Estimate based on similar projects: > $5,000/year
			> $2,500,000	> $5,000/year

Based primarily on the initial costs and for communication links between TDC and TMC as well as BATA the most efficient and cost effective solution is Managed Services, specifically frame relay, which is available from several local Service Providers.

7.3 TDC TO OTHER JPA AGENCIES AND CHP

Technology Options	Advantages	Disadvantages	Capital Cost	Operating Cost
Managed Services Frame Relay	• Service available at all sites from multiple providers • Scalable bandwidth as needs change • Reliable • High availability	• Ongoing operation costs are high and are usually locked into multi-year contracts	Network Equipment and Installation Cost: \$3,500/site (3 sites)	Recurring monthly charges: Circuit: \$500/site Maintenance/Monitoring: \$200/site Total: \$700/site/month for T1 data rates
			\$10,500	\$25,200/year
Internet Connection	• Provide capability for JPA and CHP to access management reports, etc.	• Limited 2-way access	• Fixed server /router cost \$5,000	• Approx \$250/mon for broadband connection
			\$5,000	\$3,000/year (secure hosting)

Since the data shared over this link not used in real time, and the data is not used for operational purposes the evaluation of communications options for external communications very clearly led to an inexpensive internet solution.

7.4 TOLLING ZONE TO TOLLING ZONE (REDUNDANT CONNECTIONS)

Technology Options	Advantages	Disadvantages	Capital Cost	Operating Cost
WiMAX (In combination with Fixed Wireless)	• High data rates and longer distances are achievable • Relatively low capital costs and no operational costs • Reliable (99.99%) • If primary communications connection to TDC is lost this link can be used as a fail over path to adjacent link • Link can be used for communication to vehicle detection stations located between Tolling Zones where LOS or NLOS is available	• Requires line-of-sight or near line-of-sight between end points which is not available between the North and Central Tolling Zones • Antenna structures height requirements may be an impediment • Other techniques to mitigate line-of-sight requirements adds complexity to connections (i.e. repeaters)	Equipment and Installation Costs: $25,000 per endpoint (hut, antenna structure, power, transmission equipment) (2 sites)	No recurring costs except for ongoing maintenance and support
			$50,000	$3,000/year
Fixed Wireless (T1 data rate-In combination with WiMAX components as above)	• Service is currently available from two WISP at each Tolling Zone location • Reliable	• Monthly operational costs • Viability of Wireless ISP companies	Installation Cost: $1,000/site (2 sites)	Recurring monthly charges: $400/site (2 sites)
			$2,000	$9,600/year
Fiber	• Reliable, secure and mature technology • Opportunity to partner with other agencies to share capital costs in exchange for use of dark fiber along corridor	• High capital costs • Extensive civil work required to place conduit within the median or in shoulder.	North Tolling Zone to Central Tolling Zone: 4.23 miles @$350k/mile: $1,500,000 Central Tolling Zone to South Tolling Zone: 2.83 miles @$455,000/mile: $1,300.000	No recurring costs except for ongoing maintenance and support. $1,000/PM
			$2,800,000	$12,000/year

In evaluating a backup communications link it is recommended that a combination of Fixed Wireless and WiMAX be used. Point to point WiMAX from the Central TZ to the South TZ would provide a secure, reliable and high data rate link with relatively low operating costs. It would be possible to mitigate a portion of the initial capital costs if the WiMAX infrastructure is integrated with the TZ communications facilities. For the Central TZ to North TZ, Fixed Wireless would provide a cost effective redundant communications link.

7.5 INTRA-TOLLING ZONE COMMUNICATIONS

Technology Options	Advantages	Disadvantages	Capital Cost	Operating Cost
Fiber	• Secure, reliable and mature technology • Available capacity for future	• High capital costs • Extensive civil work required to place conduit within the median or in shoulder.	$20,200	$4,000/year
Twisted Pair	• Terminal equipment is lower in cost • Ease of installation and maintenance	• Limited bandwidth for future implementation of CCTV	$6,800	$1,400/year
Wi-Fi	• Reduced capital costs since no infrastructure is required • Secure, reliable • Equipment costs are relatively low	• Public spectrum (2.4GHz or 5.8GHz) is susceptible to interference • Wi-Fi has limited P2P coverage • LOS required	$9,550	$1,200/year

The following assumptions were made in order to develop the above costs or Intra-Tolling Zone communications:

- The coverage for any intra-TZ communications infrastructure is 0.5 mile per tolling zone. This has an impact on the distance requirements for any wireless equipment and the costs related to the installation of any underground plant such fiber or twisted pair.
- TZC plus three other equipment installations (DMS, reader, VDS, CCTV).
- Low end cost estimate used for infrastructure under the assumption there will already be civil work in the area and paving will be priced in separate budget.
- 802.11g wireless - central WAP with omni-directional antenna and three bridge locations.

Based on evaluating advantages and disadvantages of the different communication options for Intra-Tolling Zones, Wi-Fi is recommended. Although the initial equipment costs may be higher, Wi-Fi can accommodate the addition of multiple future CCTV cameras within the TZ.

7.6 VDS COMMUNICATION LINKS

For the remote VDS installations that are outside the area covered by the intra-tolling zone communication infrastructure, an alternative means of communications must be utilized. Caltrans currently uses 56kbps leased lines for similar detector stations along I-680. Communications mode for the mixed flow lane VDS stations would use broadband wide area wireless networks such as EV-DO, HSDPA or EDGE/GPRS

Technology Options	Advantages	Disadvantages	Capital Cost	Operating Cost
Leased Line (Direct to TDC)	• Secure, reliable and mature technology • Available capacity for future	• Bandwidth limited by cost • Recurring monthly costs	Terminal Equipment and Construction: $1,200/site (24 sites)	Monthly service charge: $55/line (24 lines)
			$28,800	$15,840/year
Data Transmitted over Cellular GPRS/EDGE Technology	• Terminal equipment is lower in cost • Ease of installation and maintenance	• Not all areas of the corridor have sufficient coverage • Suitable for occasional outgoing calls but not for near real-time detector counts • Reliability and availability limited • Not recommended for existing environment	Terminal Equipment and Construction: $1,200/site (24 sites)	Service charge: $80/site/mon unlimited data
			$28,880	$23,040/year
Additional (MFL)VDS Data Transmitted over mobile HSDPA/EVDO	• Terminal equipment is lower in cost Ease of installation and maintenance • Suitable for near real-time detector counts •	• Not all areas of the corridor have sufficient coverage • Reliability and availability limited	Terminal Equipment and Construction: $1,200/site (14 sites)	Service charge: $80/site/mon unlimited data
			$16,800	$13,440/year
Wi-Fi (To the closest Toll Zone- and use existing	• Reduced capital costs since no infrastructure is required • Secure, reliable	• Public spectrum (2.4GHz or 5.8GHz) is susceptible to interference	Transmission Equipment and Installation for TZC, DMS and two local	No recurring costs for ongoing maintenance and support $150/per

Technology Options	Advantages	Disadvantages	Capital Cost	Operating Cost
Toll Zone- TDC network)	• Equipment costs are relatively low • Suitable for short range • Would be brought back to nearest Tolling Zone	• Near LOS required	detector stations: $7,500/TZ (3 zones)	site/per month.
			$22,500	$5,400/year
Fiber	• High reliability • High capacity • Capacity can be shared with other services/users.	• Prohibitive initial costs • Approx 14 miles of fiber installation on side of corridor	North Tolling Zone to Central Tolling Zone: 4.23 miles @$350,000/mile: $1,500,000 Central Tolling Zone to South Tolling Zone: 2.83 miles @$455,000/mile: $1,300,000 South Tolling Zone to Southern limit of SMART Lanes: 5.23 miles @$455,000/mile: $2,400,000	Maintenance fiber at corridor per year is >$200,000
			$5,200,000	$200,000

Analysis of advantages and disadvantages of the above options, in concert with cost & reliability has led to the leased line option, being clearly the optimum solution for this link. Data transmitted over Cellular is recommended as an alternative for any remote locations where leased lines may not be readily available from the phone company providing local loop service.

8. RECOMMENDATIONS

Based upon the current conditions and the criteria identified in Section 2.3, the following are the recommended communications solutions for each portion of the network. In arriving at this recommendation, the specific components for each of the segments scored the highest points in the evaluation which is summarized in the following table.

	Criteria/Weight			
	Performance Requirements	**Initial Capital Cost**	**Operating Cost**	
Communications Link/Technology	**Weight=3**	**Weight=2**	**Weight=2**	**Score**
Tolling Zone to TDC (Primary)				
Managed Services (Frame Relay)	8	9	9	**60**
WiMAX	6	5	7	42
Fiber	7	1	3	29
Shared Fiber	7	2	3	31
TDC to TMC and TDC to BATA				
Managed Services (Frame Relay)	8	9	7	**56**
Fiber	7	1	3	29
TDC to Other JPA Agencies and CHP				
Managed Services (Frame Relay)	8	9	7	56
Internet Connection	9	9	9	**63**
Tolling Zone to Tolling Zone (Redundant)				
WiMAX	6	5	9	**46**
Fixed Wireless	7	7	7	**49**
Fiber	7	1	3	29
Intra-Tolling Zone				
Fiber	7	1	3	29
Twisted Pair	3	9	7	41
Wi-Fi	6	7	7	**46**
VDS Communication Links				
Leased Line	7	9	7	**53**
Data Transmitted Over Cellular	7	9	7	**53**
Data Transmitted Over Mobile	7	9	7	**53**
Wi-Fi	6	7	9	50
Fiber	7	1	3	29

Notes:

1. For each of the communication links each technology was given a rating on a scale of 1 to 10 for each criterion. A score was then calculated based on the sum of each rating multiplied by the criteria weighting factor. The maximum score is 70.
2. The weight given to each of the criteria indicates the relative importance of each criterion in the selection of a communications technology. In this evaluation highest importance was given to meeting the performance requirements and equal importance was given to both the initial capital cost and operating costs.
3. The score for capital and operating costs for a particular communications technology was given relative to the costs of the other technologies evaluated for that specific Communications Link only. The lower the cost the higher the relative score.

This resulted in a combination of technologies and services for each segment of the overall end-to-end communications solution.

Communications Link	Recommendation	Capital Cost	Operating Cost (Annual)	Notes
Tolling Zone to TDC (primary)	Frame relay – T1 Data Rate	$10,500	$25,200	
TDC to TMC and TDC to BATA	Frame Relay – T1 Data rate	$10,500	$25,200	
TDC to Other JPA Agencies and CHP	Internet Connection	$5,000	$3,000	
Tolling Zone to Tolling Zone (redundant)	WiMAX – Central to South Fixed Wireless – Central to North	$50,000 $2,000	$3,000 $9,600	WiMAX not viable for Central to North link due to terrain
Intra-Tolling Zone	Wi-Fi	$9,550	$1,200	Wi-Fi can accommodate future CCTV
VDS Communication Links	56kbps Leased Line (assumes 24 sites)	$28,800	$15,840	Data over Cellular would be viable where leased line service is not available
MFL VDS Communications links	Broadband Wireless (14 Sites)	$16,800	$13,440	Wireless broadband to TDC
	Totals:	**$133,150**	**$96,480**	

It is recommended that as part of the Smart Lane system design (i.e. the development of the Smart Lane system RFP), the cost estimates and various options presented herein should be re-visited to ensure the best possible communication links are deployed. The costs identified are as of June 2005, including equipment and installation, but exclusive of civil work and other infrastructure costs.

In conclusion, the recommended communications solutions meet the performance requirements as well as provide the most cost-effective and state-of-the-practice technology solution as of this writing.

APPENDIX A

WIMAX COMMUNICATION

PRELIMINARY LINE-OF-SIGHT SURVEY

Tolling Zone Path Profiles

A link from the TDC to the North or Central Tolling Zone, which are about 26 miles from the TDC, would require great tower heights (1850ft and 200ft) in order to provide adequate fresnel clearance for the RF signal. A repeater at the highest point between the sites would reduce the need for high towers or mounting structures.

An alternate solution, installing a link from the TDC to the South Tolling Zone, which is about 28 miles from the TDC, would require the least amount of tower height. Links could then be established from the South Tolling Zone to the Central Tolling Zone with reasonable tower heights, but higher towers would be needed from the Central Tolling Zone to the North Tolling Zone due to the large hill that along this path. A repeater could be used here to reduce the requirement for large towers.

Presented below are preliminary Path Profiles for the following point-to-point sites:

- TDC to the North Tolling Zone;
- TDC to the Central Tolling Zone;
- TDC to the South Tolling Zone;
- South Tolling Zone to the Central Tolling Zone; and
- Central Tolling Zone to the North Tolling Zone.

The notes presented below pertain to each of the following Path Profiles.

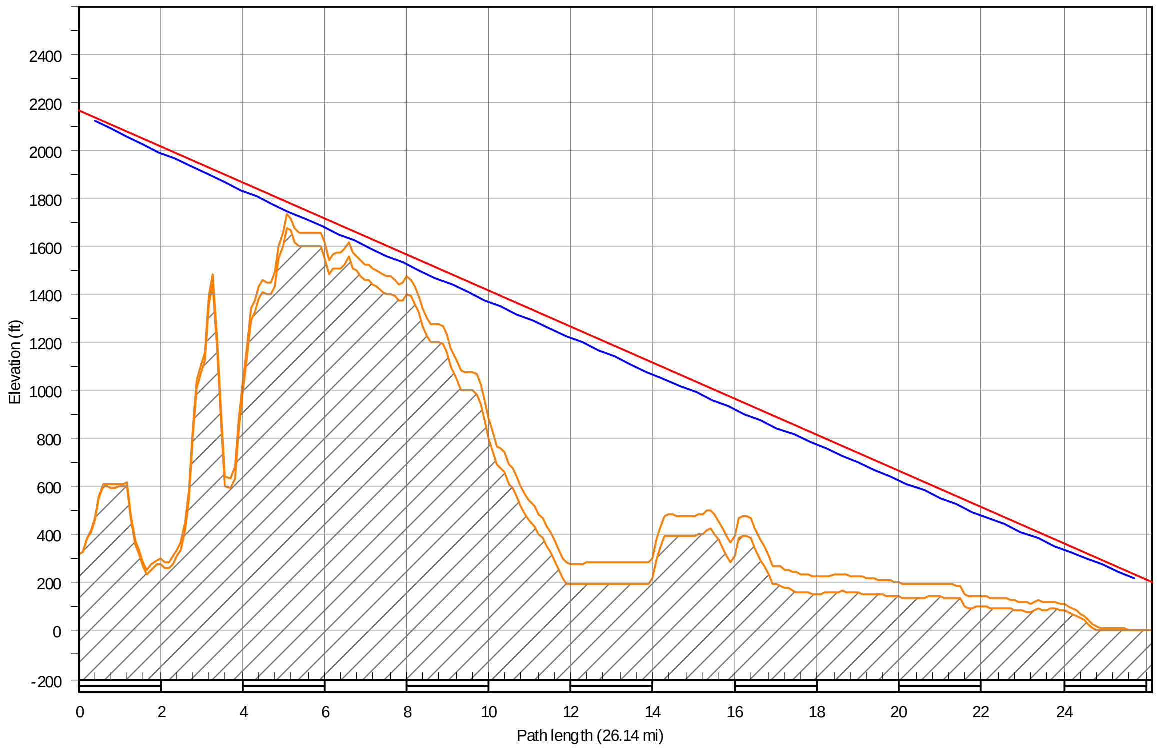
Note 1: No building heights were obtained, therefore, no assumptions were made for building heights or structures and/or obstacles along the communications link path.

Note 2: Bandwidth requirements for each communications link path were not specified.

Note 3: These path profiles have been generated using the latest terrain data as well as information, deemed accurate, provided by the customer. No assumptions were made regarding structures or obstacles along the communications link path. Therefore, each path must be visually verified.

Note 4: These Path Profile diagrams, although not specific to any particular make or model of transmission equipment, were prepared by a specific equipment vendor based on our inquiries.

TDC to North Tolling Zone



North Tolling Zone	
Latitude	37 34 41.66 N
Longitude	121 53 16.44 W
Azimuth	306.82°
Elevation	315 ft ASL
Antenna CL	1850.0 ft AGL

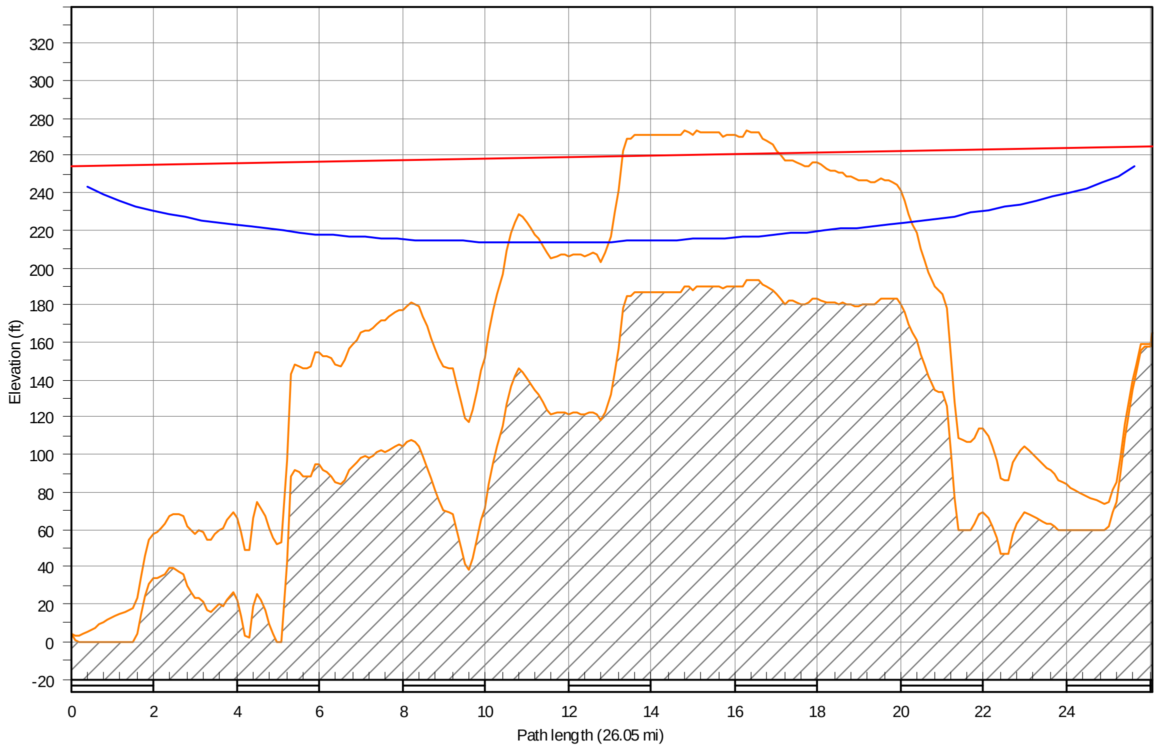
Frequency (MHz) = 5800.0
K = 1.33
%F1 = 60.00

Tolling Center	
Latitude	37 48 17.06 N
Longitude	122 16 12.97 W
Azimuth	126.58°
Elevation	4 ft ASL
Antenna CL	200.0 ft AGL

Redline Communications

I-680 Pilot Project	May 08 05	mjd
Tolling Center to North Tolling Zone	I-680-1	

TDC to Central Tolling Zone



Tolling Center

Latitude	37 48 17.06 N
Longitude	122 16 12.97 W
Azimuth	135.77°
Elevation	4 ft ASL
Antenna CL	250.0 ft AGL

Frequency (MHz) = 5800.0
K = 1.33
%F1 = 60.00

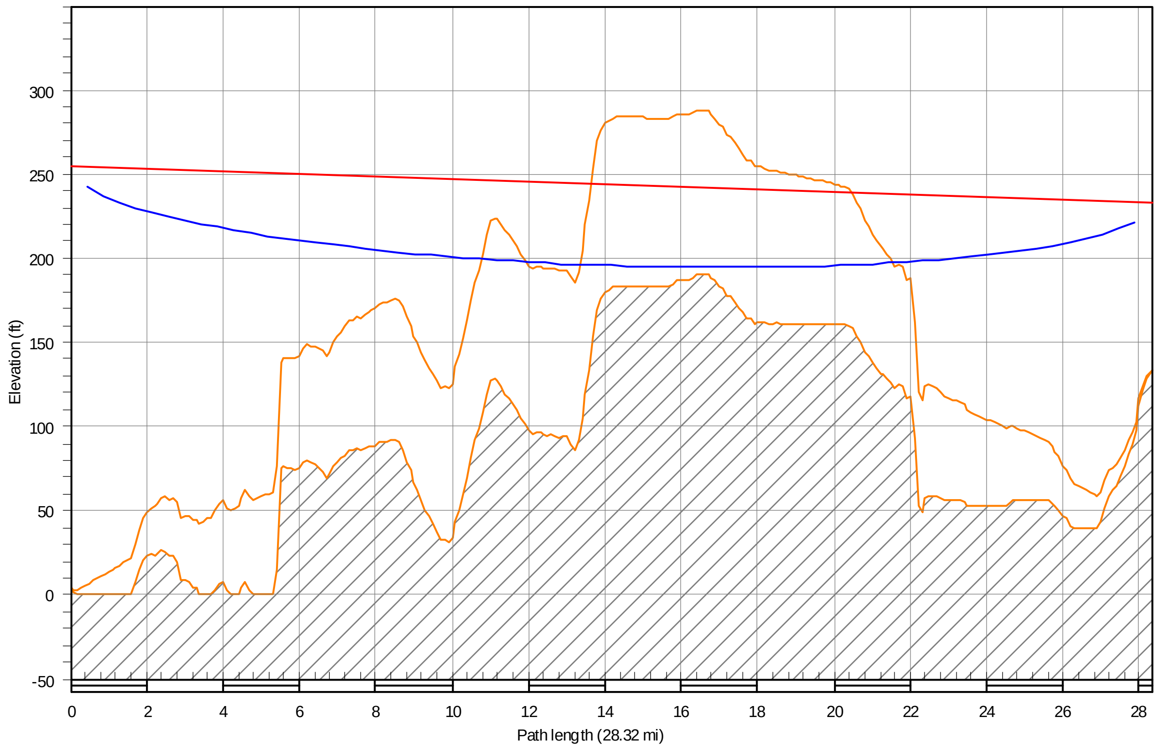
Redline Communications

Central Tolling Zone

Latitude	37 32 01.07 N
Longitude	121 56 22.13 W
Azimuth	315.98°
Elevation	165 ft ASL
Antenna CL	100.0 ft AGL

I-680 Pilot Project	May 08 05	mjd
Tolling Center to Central Tolling Zone	I-680-2	

TDC to South Tolling Zone



Tolling Center	
Latitude	37 48 17.06 N
Longitude	122 16 12.97 W
Azimuth	137.97°
Elevation	4 ft ASL
Antenna CL	250.0 ft AGL

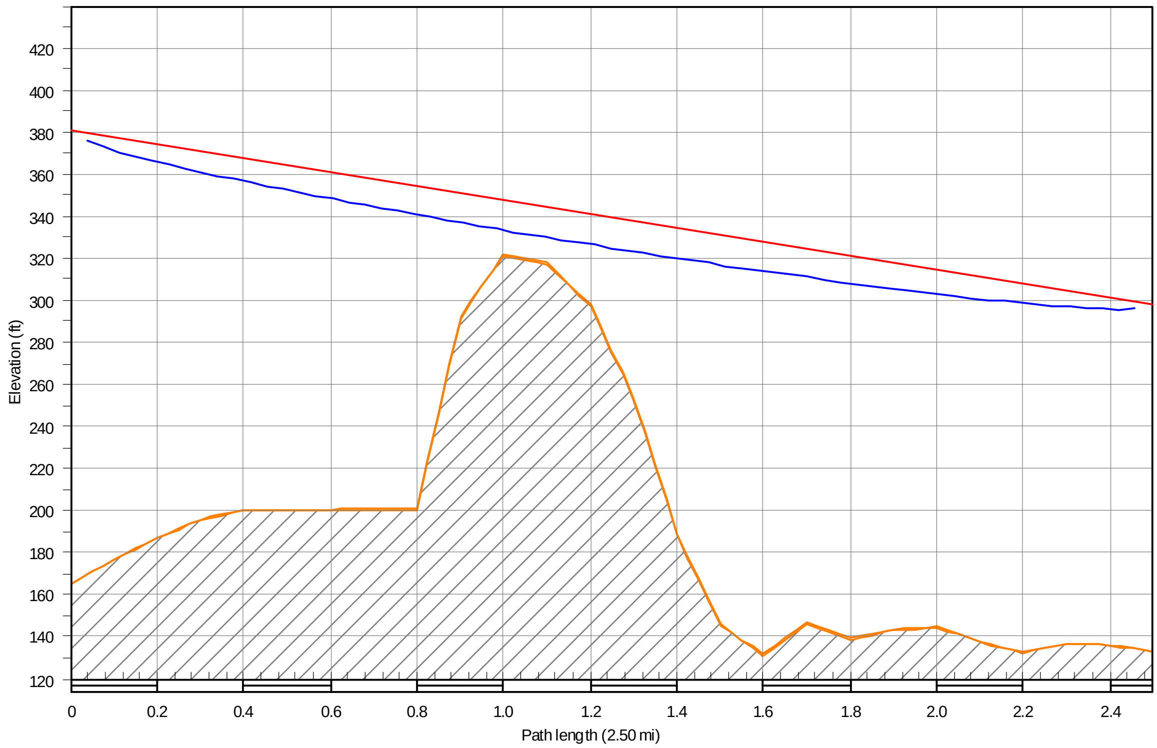
Frequency (MHz) = 5800.0
K = 1.33
%F1 = 60.00

Redline Communications

South Tolling Zone	
Latitude	37 29 57.34 N
Longitude	121 55 30.97 W
Azimuth	318.18°
Elevation	133 ft ASL
Antenna CL	100.0 ft AGL

I-680 Pilot Project	May 08 05	mjd
Tolling Center to South Tolling Center	I-680-3	

South Tolling Zone to Central Tolling Zone



Central Tolling Zone	
Latitude	37 32 01.07 N
Longitude	121 56 22.13 W
Azimuth	161.77°
Elevation	165 ft ASL
Antenna CL	215.0 ft AGL

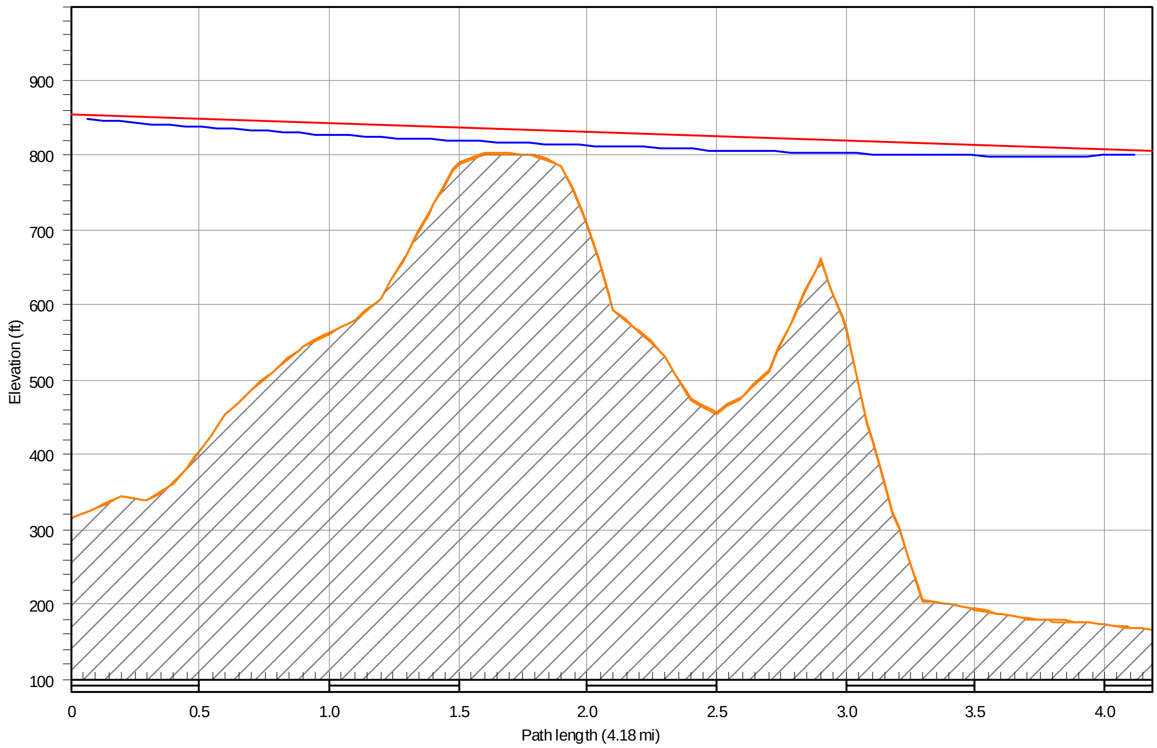
Frequency (MHz) = 5800.0
K = 1.33
%F1 = 60.00

Redline Communications

South Tolling Zone	
Latitude	37 29 57.34 N
Longitude	121 55 30.97 W
Azimuth	341.78°
Elevation	133 ft ASL
Antenna CL	165.0 ft AGL

I-680 Pilot Project	May 08 05	mjd
South Toll Zone to Central Toll Zone	I-680-4	

Central Tolling Zone to North Tolling Zone



North Tolling Zone	
Latitude	37 34 41.66 N
Longitude	121 53 16.44 W
Azimuth	222.65°
Elevation	315 ft ASL
Antenna CL	540.0 ft AGL

Frequency (MHz) = 5800.0
K = 1.33
%F1 = 60.00

Redline Communications

Central Tolling Zone	
Latitude	37 32 01.07 N
Longitude	121 56 22.13 W
Azimuth	42.61°
Elevation	165 ft ASL
Antenna CL	640.0 ft AGL

I-680 Pilot Project	May 08 05	mjd
Central Tolling Zone to North Tolling Zone	I-680-5	